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Simulation of quench in a 400 MHz RF-dipole crab cavity

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Abstract

A thermal breakdown in a 400 MHz RF-dipole crabbing cavity has been numerically modeled. Simulation results show that quench is developing in about 3 ms.

Introduction

Superconducting RF crab cavities are used in colliders, adopting finite angle crossing scheme. In this scheme non-overlapping of the beam bunches at collision point causes beam instability and limit the luminosity. The complete overlapping of the bunches at colliding point, so-called crab crossing, is implemented. RF crab cavity imparts transverse momentum to the bunch, deflecting its head and tail in opposite direction so that collision is effectively "head on" and then luminosity is maximized.

Quench – a process of rapid loss of superconducting state – in SRF crab cavity can lead to loss of the beam. One way to avoid this is to detect quench and direct the beam to a dump. In order to implement this procedure it is important to understand its dynamics.

Simulation and results

A quench in RF-dipole crab cavity, starting from a thermal defect, has been simulated. Parameters of studied cavities are listed in Table 1. It was assumed that kick voltage is the same for both cavities. Additionally, the following assumptions were made:

- quench happens in a place with max B-field
- He cooling and external power supply can be neglected on the time scales of interest

The defect was modeled by a region, where surface resistance equals to surface resistance of normal conducting Nb at transition temperature. Description of the code can be found in technical note TD-11-017.

Table 1: Parameters of simulated crab cavities

Parameter	Value	Parameter	Value
Cavity Radius	140.5 mm	Peak E-field	50 MV/m
Cavity Length	775 mm	Peak B-field	86 mT
Beam Pipe	84 mm	R_T/Q	430 Ω
Frequency, MHz	400 MHz	Stored Energy	3.25 J

Simulation results are summarized in Table 2. They are quite similar for both cavities. Figure 1 shows dependence of peak field on time. All stored field is consumed in about 8 ms. Figure 2 depicts phase portrait of the process. Horizontal axis denotes normalized stored energy, consumed by quench $[P_0 - P(t)]/P_0$, the breakdown starts at time t = 0. Vertical axis is the normalized rate of energy consumption $\partial(P(t)/P_0)/\partial t$. As can be seen in Fig. 2, the time constant of the process is about 2.7 ms.

In this simulation the initial peak E-field was slightly higher than it should be (50.6 MV/m vs 50.0 MV/m), but this discrepancy should not affect the results significantly.

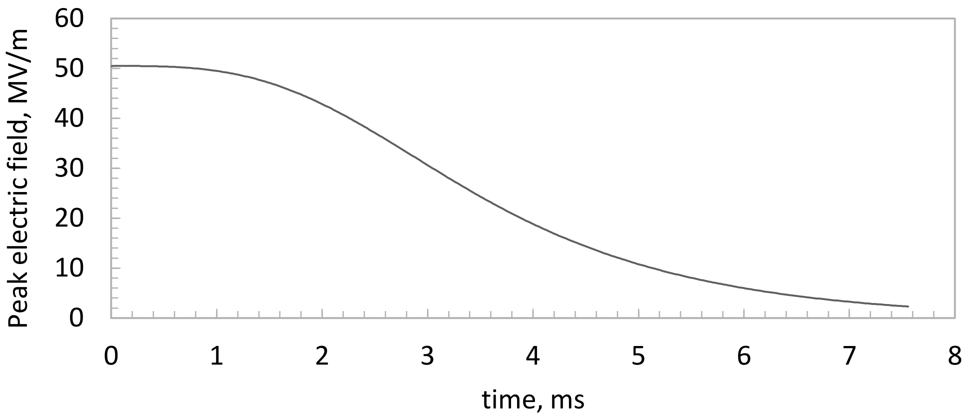

Figure 1: Peak electric field as a function of time

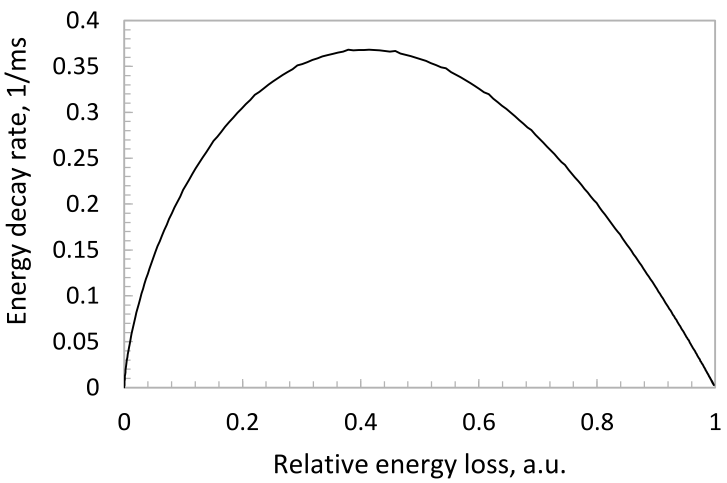

Figure 2: Phase portraits of the quench process

Figure 3 depicts temporal evolution of the radius of normal conducting zone, solid line - on the inner surface of the cavity wall, dashed line - on the outer surface. In the beginning of the process the normal zone propagation velocity is about 20 m/s. After the quench started, it takes heat about 0.5 ms to reach the outer surface of the cavity wall from the inner surface. The diameter of the hot spot produced by the quench can as high as 16 cm.

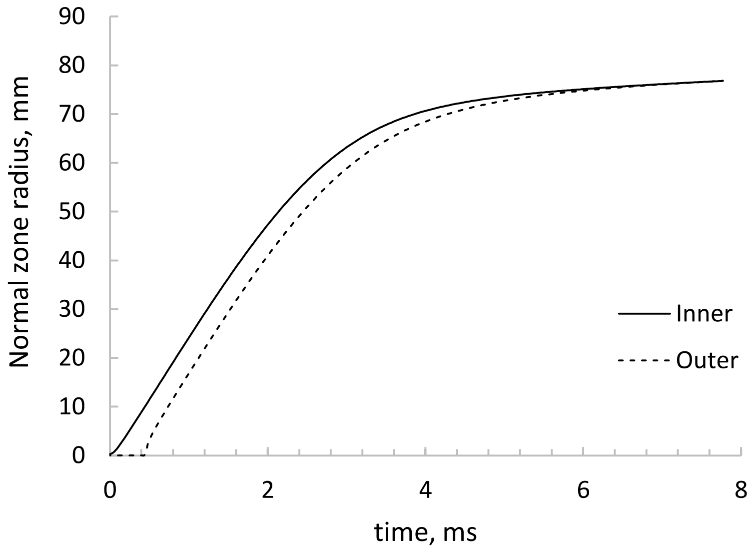

Figure 3: Normal conducting zone radius as a function of time.
Solid line – inner surface, dashed – outer.

Table 2: Simulation parameters and results

Parameter	400 MHz RF-Dipole
Material	Nb, RRR = 300
Helium temperature	2 K
Cavity wall thickness	4.0 mm
Initial peak E-field	50 MV/m
Radius of thermal defect	0.3 mm
Time constant of energy consumption	3 ms
Max growth rate	20 m/s
Max radius of normal conducting zone	8 cm

Conclusion

Breakdown in 400 MHz RF-dipole crab cavity has been numerically simulated. Results show that in these cavities a characteristics time constant of energy decay is 3 ms. Maximal normal zone propagation velocity is 20 m/s, and the size of resulting hot spot is about 16 cm.